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Microbial Aerosols: Estimated Contribution of Combine Harvesting to an Airshed

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From plate counts of the airborne microorganisms in the downwind dust plume of operating grass-seed combines, the mean source concentrations were calculated to be 6.4×10^8 and $4.7 \times 10^8/m^3$, respectively, potentially accounting for at least 41.9% of the bacteria and 35.1% of the fungi in the airshed in the Willamette Valley, Oregon.

Microorganisms are contributed to the rural atmospheric load from natural macroscale processes such as atmospheric frontal activities (7), whose influence on loading has been measured over intercontinental distances (2, 14), and mesoscale man-made processes associated with loadings in urban air masses (8) and with loadings from agricultural crops (17) in rural air masses. Many microscale processes further complicate the rural loading by the injection of sporadic clouds of aerosolized microorganisms from various sources such as swine houses (3, 4) and cattle (18), whereas monoculture crops may contribute their own peculiar flora including pathogens (11) to the load (5, 13). Reviews of various aspects of rural aerobiology have been presented previously (6, 9, 12, 16).

It is known that harvesting machinery generates large amounts of dust (1), but there is little published information on the contribution of these machines to the microbial loading of the rural atmosphere (15). This is particularly pertinent in the Willamette Valley, Oregon, where agricultural activity generates large amounts of dust in a relatively closed airshed. Airflow in the Valley is severely restricted horizontally by the Coastal and Cascade Mountains and vertically by a stable inversion layer that forms on summer days. Nighttime onshore ocean winds usually clear the stagnant air masses.

The question arises as to how much do the various agricultural activities contribute to the atmospheric load in the Willamette Valley. This is a report of some measurements of the bacterial and fungal atmospheric loadings in and about downwind plumes from agricultural combine and grass hay-harvesting operations and some implications for the local atmospheric environment.

Media. Bacteria were grown on a medium consisting of (per liter of distilled water): peptone (50 g), yeast extract (1.0 g), ferric phosphate (0.01 g), and agar (15 g), adjusted to pH 7.2. Cycloheximide and nystatin were added to give a final concentration of 50 μg/ml of medium. Fungi were grown on Czapek Dox agar (Difco Laboratories, Detroit, Mich.) supplemented with 30 μg of chlortetracycline per ml. All antibiotics were filter sterilized and added to the cooled (45°C) agar after being autoclaved at 121°C for 15 min. Incubation was at 25°C for 10 days in plastic bags with the plates inverted to conserve moisture in the agar.

Sampler. A slit sampler (model 200; Mattson-Garvin Co., Maitland, Fla.) with a clock motor (1 revolution per 0.25 h) was calibrated to draw 1,042 liters of air per h through a 0.152-mm slit positioned 2 mm above the agar surface. The sampler power source was a 3,000-W, 112-V, 60-cycle gasoline-driven generator. The sampler was located away from obstructions and ca. 2 m above the flat terrain on the western or onshore wind edge of the floor of the Willamette Valley, Oregon, in the downwind plume path perpendicular to moving harvesting machines. A 0.25-h continuous sample through the plume including preplume and postplume measurements, was collected for each observation, i.e., 265 liters. The plume arrival time was also recorded.

Preplume measurements were used as control observations since (i) the winds were onshore from the ocean, (ii) there were no upwind combines possible in the sample area, and (iii) measurements were taken early in the combine workday after replacement of the stagnant air masses by nighttime winds.

Harvesting machinery. The combines generating the microbial aerosols were John Deere models 6600 or 7700 (Moline, Ill.) or Massey-Ferguson model 760 (Toronto, Ontario, Canada). The four-bladed fans on the combines had dimensions of 133 by 15.2 cm and were run at 860 rpm. The grass hay baler was a New Holland (Holland, Pa.) model 273 with a chamber measuring 40.6 by 45.7 by 76.2 cm and a plunger stroke rate of 90 strokes per min. All machines were isolated from other obvious aerosol sources except the John Deere 7700s which were operated as a gang of five machines.

Calculations. Source concentrations (SC) of microorganisms were estimated by using geometric considerations that assumed that the plume was semicone shaped with the source machine at the vertex and the air sampler at the midpoint of the base (measured distance, AB; see equations 1 through 5). Assumptions were also made that the source machine was running perpendicular to the wind at 4.8 km/h for the combines and 0.6 km/h for the baler (10) and that all microbe-bearing particles generated by the sources were uniformly diluted and remained suspended in the air until the receiving air mass passed the sampling location. The latter assumption yields conservative estimates of the source strength, since gravitational processes will tend to decrease the particle density with distance from the source and height in the semicircular-appearing plume, but this is presumably minimal with winds above 1 m/s.

$$\text{SC} = \text{measured microbial load} \times \text{plume dilution factor (DF)} \quad (1)$$

$$\text{DF} = \text{plume volume (VP)}/\text{machine fan or stroke volume output (VS)} \times (\text{AB}/\text{wind speed}) \quad (2)$$

$$VP = [(B/2)^2 \times \pi/3] \times AB/2 \quad (3)$$

B = machine speed × measured time sampling within plume (4)

VS = volume of fan or chamber output × rpm (5)

The potential mean load of microorganisms (M) that could be contributed to the Willamette Valley airshed (VA) by all grass-seed combines in the Valley was estimated by using equations 6 through 9 as follows:

M = estimated mean valley airshed microbial load contributed by the combined Valley combines (NMO)/VA (6)

NMO = total Valley combine fan outputs (VC) × SC (7)

VC = VS × number of combines (NC) (8)

NC = total area of grass-seed harvested/area harvested in a 10-h day by one combine/number of harvesting days (9)

It was assumed that (i) there were 13,000 ha (13×10^7 m^2) of grass-seed harvested (personal communication, Oregon Seed Council) over 30 10-h harvesting days with combines operating at 10.12 ha/day (10.12×10^4 m^2/day), (ii) the Willamette Valley airshed was 195 km long and 150 km wide (from the Coastal to Cascade mountain range ridges), and (iii) there was either a 335-m minimum or 1,684-m mean inversion height (for nonrainy, July or August days at 1600 h [personal communications, Oregon Seed Council and Oregon State Department of Environmental Quality]).

The percentage of contribution to the microbial load in the airshed due to combine harvesting = the maximum (or minimum) value in the set of all estimated mean airshed loads (M; equation 6)/minimum of measured before or after microbial loads (Table 1).

In combine plumes, the measured density of fungi ranged from 3,310 to 33,740 CFU/m^3 and that of bacteria ranged from 3,923 to 18,520 CFU/m^3 for various distances upwind (Table 1), with ca. 10,530 fungi per m^3 and 3,450 bacteria per m^3 in the plume produced by the combine auger during the unloading operation 100 m upwind. The mean fungal and bacterial densities in the dust plume from a grass hay-baling operation 15 m upwind were 2,830 and 4,410 CFU/m^3, respectively. These are considered to be conservative measurements as are the calculations derived from them because of the potential inefficiency of the sampler and the nonuniformity in the dust plume before sampling.

The potential contribution of the combine inputs alone to the Willamette Valley microbial load was calculated based on (i) the conservative estimate of the mean source concentration (equations 1 through 5) of 6.4×10^8 bacterial CFU/m^3 and 4.7×10^8 fungal CFU/m^3, (ii) the total number of microorganisms produced by all combines in the Valley during 1 harvest day, and (iii) the assumption that the aerosols were contained and evenly dispersed in the Valley airshed. The mean of the estimated loadings for the sample set put the microbial concentrations at 182 and 122 CFU/m^3 for a 1,684-m inversion height and at 918 and 611 CFU/m^3 for a 335-m inversion for viable bacteria and fungi, respectively

TABLE 1. Airborne bacterial and fungal loads in the air of rural Willamette Valley, Oregon, before, during, and after visually observed arrival of the dust plume at a site downwind from operating grass-seed combines and a grass hay baler

Source machine model[a]	Date (h)	Trial	Downwind distance (m)	Wind speed (m/s)	Microbial load (CFU/m^3)			Estimated source strength (CFU/m^3)[b]
					Before	During	After	
Fungi								
Combine								
MF 760	23 July 82 (1320)	1	100	4.5	1,780	31,500	3,250	2.4×10^8
JD 6600	20 July 82 (1830)	1	150	4.2	2,900	33,740	4,085	6.3×10^8
	20 July 82 (1845)	2	150	4.2	4,085	9,655	3,490	2.7×10^8
JD 7700	10 July 82 (1210)	1	1,500	1.6	165[c]	3,310	165[c]	7.2×10^8
Combine unloading MF 760	23 July 82 (1300)	1	100	4.5	2,170	10,530	1,890	8.2×10^7
Baler NH 283	19 July 82 (1315)	1	15	3.1	1,440	3,310	1,450	4.4×10^6
	19 July 82 (1330)	2	15	3.1	1,450	2,340	1,451	6.6×10^6
Bacteria								
Combine								
MF 760	23 July 82 (1330)	1	100	4.5	1,829	9,654	1,970	4.2×10^8
JD 6600	20 July 82 (2000)	2	300	3.7	5,671	8,211	3,870	2.8×10^8
	20 July 82 (2015)	1	300	3.7	3,870	18,520	4,771	1.0×10^9
JD 7700	10 July 82 (1210)	1	1,500	1.6	237	3,923	237	8.6×10^8
Combine unloading MF 760	23 July 82 (1330)	1	100	4.5	953	3,450	819	1.5×10^8
Baler NH 273	19 July 82 (1315)	1	15	3.1	643	6,660	865	1.9×10^7
	19 July 82 (1330)	2	15	3.1	865	2,150	643	3.3×10^6

[a] MF, Massey-Ferguson; JD, John Deere; NH, New Holland. All the machines were used alone except the John Deere 7000s which were operated as a gang of five machines.

[b] The mean estimated source strengths (CFU per cubic meter) for the combines are 4.7×10^8 (fungi) and 6.4×10^8 (bacteria) and for the balers are 5.5×10^6 (fungi) and 1.1×10^7 (bacteria).

[c] Mean value for 50 days previously sampled.

(equations 6 through 9). Thus, a conservative maximum estimated contribution to the airshed bacterial and fungal microflora within the sample set of 7.0 and 8.3%, respectively, may be the result of combine harvesting operations during mean inversion conditions. For minimum inversion conditions, from 8.5 to as much as 41.9% and from 10.5 to 35.1% of the Valley mean bacterial and fungal atmospheric loads, respectively, might be accounted for by grass-seed combine harvesting. It must be remembered, since the newly formed clouds of aerosolized microorganisms do not mix throughout the airshed, that one could expect local concentrations of microorganisms that might be less than, equal to, or exceed the calculated mean airshed values.

Finally, if combine harvesting in fact contributes a large proportion of the rural atmospheric loading of microorganisms, then what are the sources of the remaining loadings and how do the rates of injection and removal influence the day-to-day loadings? And further, how do the rural loadings affect plant epidemiology and human allergenic responses?

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